

## AIRBUS WINDSHEAR WARNING AND GUIDANCE SYSTEM

### 1. AIRBUS WINDSHEAR PHILOSOPHY

From its first designed airplane, Airbus considered mandatory an help in the crew's decision-making process to initiate an escape manoeuvre and an help to successfully realize it.

For doing so forth all the Airbus airplanes are designed since 1975 including alpha-floor function and speed reference control law imbedded in the SRS box for A 300 and FAC and FCC for A 310, A300/600 and the A 320.

Alpha-Floor function takes into account airplane energy situation considering angle of attack and observed longitudinal situation in order to apply immediately the full power without any pilot action.

Speed reference managers airspeed and/or ground speed in order to survive a maximum in shear situation.

In order to comply with the new FAA regulation: Aerospatiale and Airbus developed more efficient new systems.

The following part of this presentation is a comparison between 1975 and newly developed system and explains how the new system does improve the situation.

### 2. WINDSHEAR GUIDANCE STRATEGIES

Analog A 300's and digital A 310's and A 300-600's (AFCS standards 5-6-7) have a very well known and similar SRS guidance law (Basic 1975 situation).

From our experience we confirm that this strategy is precise enough to survive many shears. In some strong shear cases it is however completed by an OEB procedure for disregarding FD bars at some point.

Safetywise analog and digital systems also do comply with the AC 25.12.

The basic Airbus Windshear guidance is favorable but can be improved.

We therefore defined a fully adaptive system that is able to cope with strong shears without any special procedure at all.

Initially we tried to develop an optimal guidance system but we reached very quickly for impossible solutions :

**First** : optimal guidance procedures really are different from one shear to another, in some cases the system initially even demanding to dive.

**Second** : guidance is really optimal if we have the full knowledge of the whole shear pattern before penetrating it.

**Third** : which in fact is the conclusion of the second point : in any shear encounter an optimal guidance system has to bet on the future.

For all these reasons we developed a repetitive and adaptive survival strategy (Figure 2) adapted to all performance problems in typical shear conditions.

The system is derived from the A 300 SRS System (Figure 3) improved by a vertical speed floor protection, by a Vmini protection and by a stall protection.

This Control law realizes the survival strategy (Figure 4) whatever be the longitudinal or vertical shear stressing the aircraft capability in take off or go around conditions.

The Control law implemented in the FCC's SRS take off go around mode is available on flight director, CWS or command.

In shear conditions and when shear intensity stresses the aircraft's capability, the SRS law will progressively adapt its control to a survival strategy :

- 1 - Basic vote (n°1) will control airspeed ( $V_{sel} + 10 \text{ Kt}$ ) with a vertical speed decreasing to zero.
- 2 - Vote n°2 then over controls vote n°1 and commands a slightly positive vertical speed with an airspeed decreasing down to  $V_{stick \ shaker} + \Delta$ .
- 3 - Vote n°3 then overcontrols vote n°2 and vote n°1, controls airspeed at  $V_{ss} + \Delta$ . The altitude will be reduced until the shear decreases.

Whatever commanded strategy, pitch attitude demand is limited by a stall protection to avoid impending any stall situation.

### 3 - AIRBUS GUIDANCE SITUATIONS

The most severe shears proposed in AC 120.41 windfield models were simulated in the take off phase both with the initial A 300 SRS system and with the newly developed windshear guidance system (called here control of aircraft's energy).

Comparing figures 5 and 6 we conclude that the new system really does improve the situation but that the initial A 300 SRS was already well effective in its capability to cope with a real encounter.

Figures 7 and 8 emphasize the advantages presented by the new system in theoretical shear conditions: an adaptive control law maintains the aircraft inside the operational flight envelope and uses maximum airplane capability to achieve this.

The control law is implemented in the A 300-600 AFCS since A/C MSN 420 and for the A 310 it will be in the 89 first part. In principle the control law is available for retrofit to all aircraft from the digital fleet.

From simulation experience we know that for take off with derated power or for the landing case a successful escape manoeuvre can be accomplished if max power or go around decision is promptly decided upon entering the shear.

This remark just to focus on the absolute need for a tool to trigger the crew's decision-making process to initiate escape.

Windshear detection can provide this valuable help; but what do we have to detect what nuisance warning level should we reach to maintain an acceptable level of crew confidence with regard to the warning.

All those aspects were kept in mind to define an Airbus windshear warning philosophy from in-flight incident/accident analyses.

#### 4 - AIRBUS WINDSHEAR WARNING

Airbus targets (Figure 9) enhances AC 25.12 advices in detection, non-detection and performance nuisance warnings.

An evident design philosophy with regard to warnings was to define a wind severity factor computation (SF).

$$\frac{d \text{ Energy}}{dt} = \text{Weight} \left[ C_{te} - \text{Airspeed} \times \frac{d W_x}{dt} + g \cdot W_z \right]$$

$$SF = \left[ \frac{d W_x}{dt} - \frac{g}{\text{Airspeed}} \times W_z \right]$$

Intuitively this reflects the instantaneous loss of energy due to the global shear (longitudinal & vertical) if  $SF > 0$ .

$W_x$  = longitudinal wind < 0 IF headwind

$W_z$  : vertical wind < 0 IF down

$C_{te}$  : function of A/C propulsion and aerodynamics (typical to each airplane)

$G$  : gravity acceleration

SF could be filtered and compared to a fixed threshold of 2.5 kts/sec or 0.13 g typically.

This conventionally adopted solution was however rapidly abandoned due to a high level of nuisance warnings.

Wind variations knowledge is in fact the only parameter for a shear intensity evaluation but can never be the unique information in a windshear warning without duly taking into account the aircraft's energy situation.

Windshear Warning computed without considering actual aircraft energy will lead, in certain cases of shear encounter, to very early warnings (the crew should identify them like nuisance warning) or will lead to too late warnings endangering an escape manoeuvre.

A good crew confidence level and a satisfactory escape manoeuvre capability can both be reached by a windshear warning as a reasonable compromise between "SF", aircraft's actual energy and a safe minimal energy.

## 5 - WIND SHEAR WARNING (WSW) COMPUTATION PRINCIPLE

The WSW is activated when the predicted aircraft's energy is below a predetermined minimal energy threshold (Figure 10).

This threshold corresponds to still air  $\alpha$  floor protection in accordance with Flaps and Slats position.

$$\alpha^* = \alpha + \alpha_w$$

The predicted aircraft's energy depends on  $\alpha^*$  which is obtained considering filtered angle of attack (AOA or  $\alpha$ ) corresponding to the actual aircraft's energy situation increased by equivalent angle of attack estimates (E.AOA.E)  $\alpha_w$ .

$\alpha_w$  is an estimate of the energy loss foreseeable in the close future.

Note that the higher is AOA ( $\alpha$ ) the lower is the actual aircraft energy and the higher is E.AOA.E ( $\alpha_w$ ) the higher will be the future loss of energy.

$\alpha_w$  is obtained by a combination of equivalent angles of attack estimates :

- (a) - is the E.AOA.E due to instantaneous tailwind shear
- (b) - is a memorized E.AOA.E of the recent headwind shear.

Generally a strong headwind is precursor of a strong decreasing shear.

- (c) - is an E.AOA.E decrease according to the mean wind observed in order to alleviate turbulence nuisance warnings

$\alpha^*$  - is an E.AOA.E related to the observed vertical downward wind.

a, b, c, d, E.AOA.E's cannot be negative

b minus c cannot be negative

$\alpha W = a + d + (b - c)$  if  $a > 0$

This windshear warning mechanization is schematized on figure 11.

In areas I, II and III, E.AOA.E's are computed but  $\alpha^*$  is identical to AOA since  $a \leq 0$  (no tail wind shear)

$\alpha^*$  combines AOA and  $\alpha W$

In area IV when vertical wind becomes negative :  $d > 0$ .

In area V  $\alpha W$  increases when tailwind shear appears.

In that case WSW threshold is reached. It could have been reached in area IV if vertical wind intensity would have been higher. Similarly, it could also have been reached in area V with tailwind shear depending on shear intensity.

Simulator experience shows that short after lift off below 250 ft it is useful to trigger the WSW according to the tail shear for the case of a small margin regarding to 1,2 Vs. For clarification purpose, this function is not shown on these figures but it should be reminded that from lift off to 250 ft WSW can occur from  $\alpha^*$  or from the  $\alpha$  branch only compared to a smaller threshold if  $V_c < 1,2 V_s + 5$  Kt.

## 6 - PERFORMANCE WARNING

### 6-1 - PERFORMANCE NUISANCE WARNING

We considered both take off and landing cases but we limit intentionally here our evaluation to the most disturbing case for air traffic and aircraft's utilisation : the landing case.

Nuisance warning probability by approach had been evaluated by simulating 500 automatic landings in tower wind conditions up to 40 Kts according to AC 20.57 A advices (automatic landing performance evaluation). Results are plotted figure 12.

Nuisance warning probability by approach is plotted for Airbus windshear warning and for the conventional windshear warning (properly filtered "SF" by a 4s lag refered in section 4).

We remind that a conventional windshear warning leads to a nuisance level of  $10^{-3}$  per landing with a recommended threshold of 0,13 g or 2,5 Kts/sec. We also note that the Airbus windshear warning leads to a nuisance level of  $10^{-5}$  per landing with its implemented threshold of 11,5°. It is interesting to remember here that the US in service observed windshear probability encounter is about  $10^{-5}$ .

## 6-2 - NORMAL PERFORMANCE WARNING

The Airbus WSW will alert the crew after an initial loss of longitudinal airspeed. The closer the selected airspeed to  $1.3 V_s$  the smaller this initial loss before the warning is triggered (Figure 13).

Airbus WSW merely alerts the crew but has no activity on throttles or go around. the crew will decide according to the situation to pursue or to abort when landing or to triggering max power or not at take off.

$\alpha$  Floor protection is maintained on Airbus being the ultimate protection if the crew underestimates the situation at WSW.

For a windshear encounter case the general situation of Airbus WSW and  $\alpha$  FLOOR are plotted on figure 14. One can notice the remaining energy margin at WSW and at  $\alpha$  FLOOR.

In case the pilot wrongly selects too small a speed ( $1.25 V_s$  for example) the  $\alpha$  FLOOR will in same cases of shear conditions intervene before the warning itself.

## 7 - AIRBUS WSW AND GUIDANCE IMPLEMENTATION

Since WSW is implemented in each FAC, aural and visual warnings can be tested on ground engines not running (Figure 15). In a case of shear encounter aural warning is activated and visual windshear red message displayed on each PFD. Warning can be activated at take off from lift off to 1000 ft and at landing from 1000 ft to 50 ft the visual warning will remain for a minimum of 15 s.

The general architecture is given figure 16.

## 8. A 320 IMPLEMENTATION

Aerospatiale and Airbus develop now very similar control laws for the A 320 taking advantage of managed speed "autothrottle" function for warning and guidance in order to further decrease nuisance warning level and increase safety in the escape manoeuvre initiation.

The A 320 system also takes advantage of the fly by wire concept for the guidance part.

Fly by wire controls, if necessary, the plane into its maximum lift capability in the final part of the escape while avoiding any stall situation.

Certification is expected for 1989 in order to comply with the new FAA regulation process.

# SRS STRATEGIES

## NO SHEAR CONDITIONS

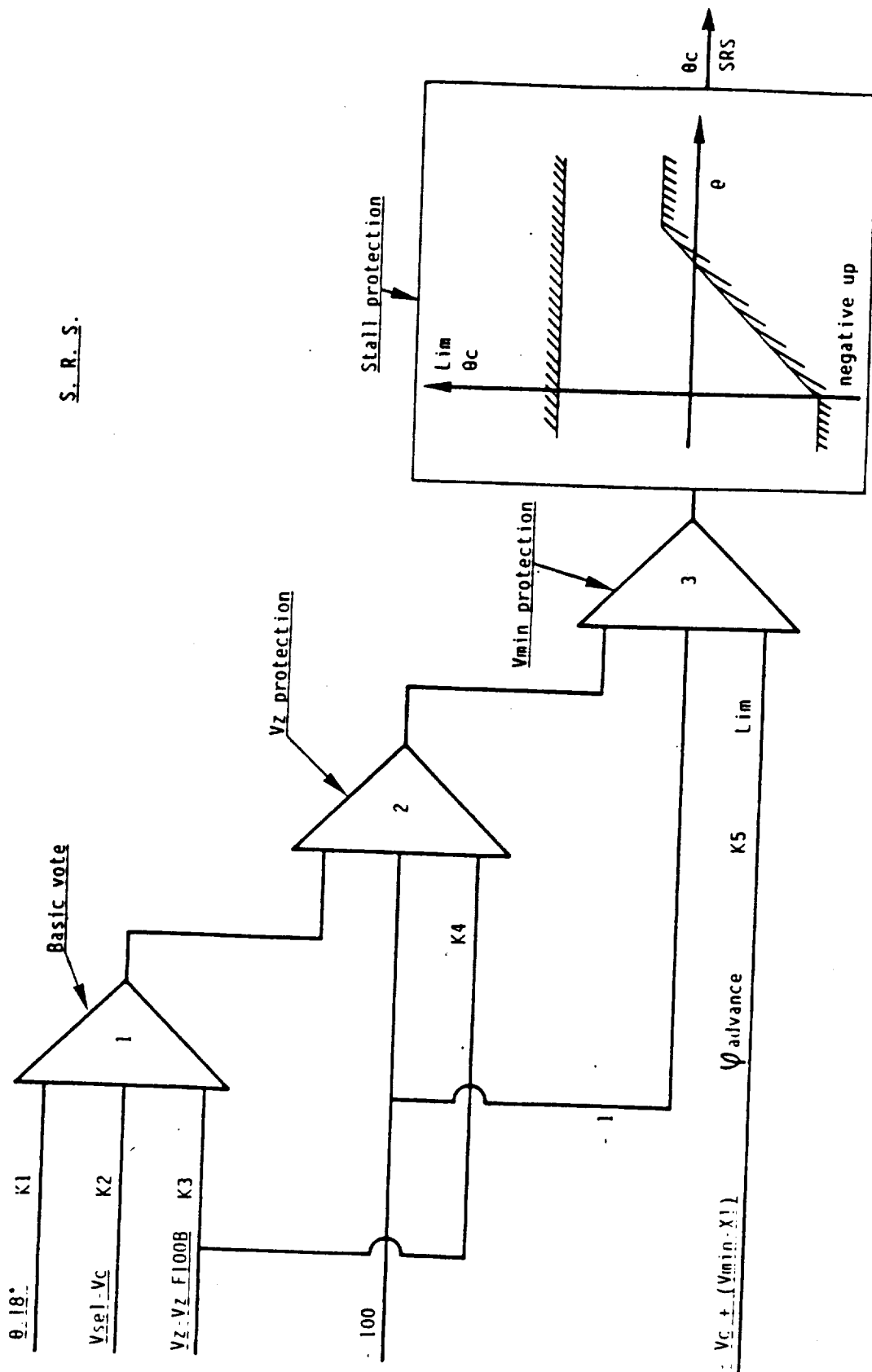
1	High thrust to  weight ratio	<ul style="list-style-type: none"> <li>• SRS controls pitch attitude</li> <li>max <math>\theta = 18^\circ</math></li> <li>• Climbing slope = cte</li> <li>• VC increases <math>&gt; V_2 + 10</math> Kts</li> </ul>
2	Low thrust to  weight ratio	<ul style="list-style-type: none"> <li>• SRS controls airspeed</li> <li>VC = <math>V_2 + 10</math> Kts</li> <li>(VC = <math>V_2</math> or VEF if <math>VEF &gt; V_2</math>) EF case</li> <li>(Vertical speed <math>&gt; 2,4\%</math> , <math>\theta &lt; 18^\circ</math>)</li> </ul>

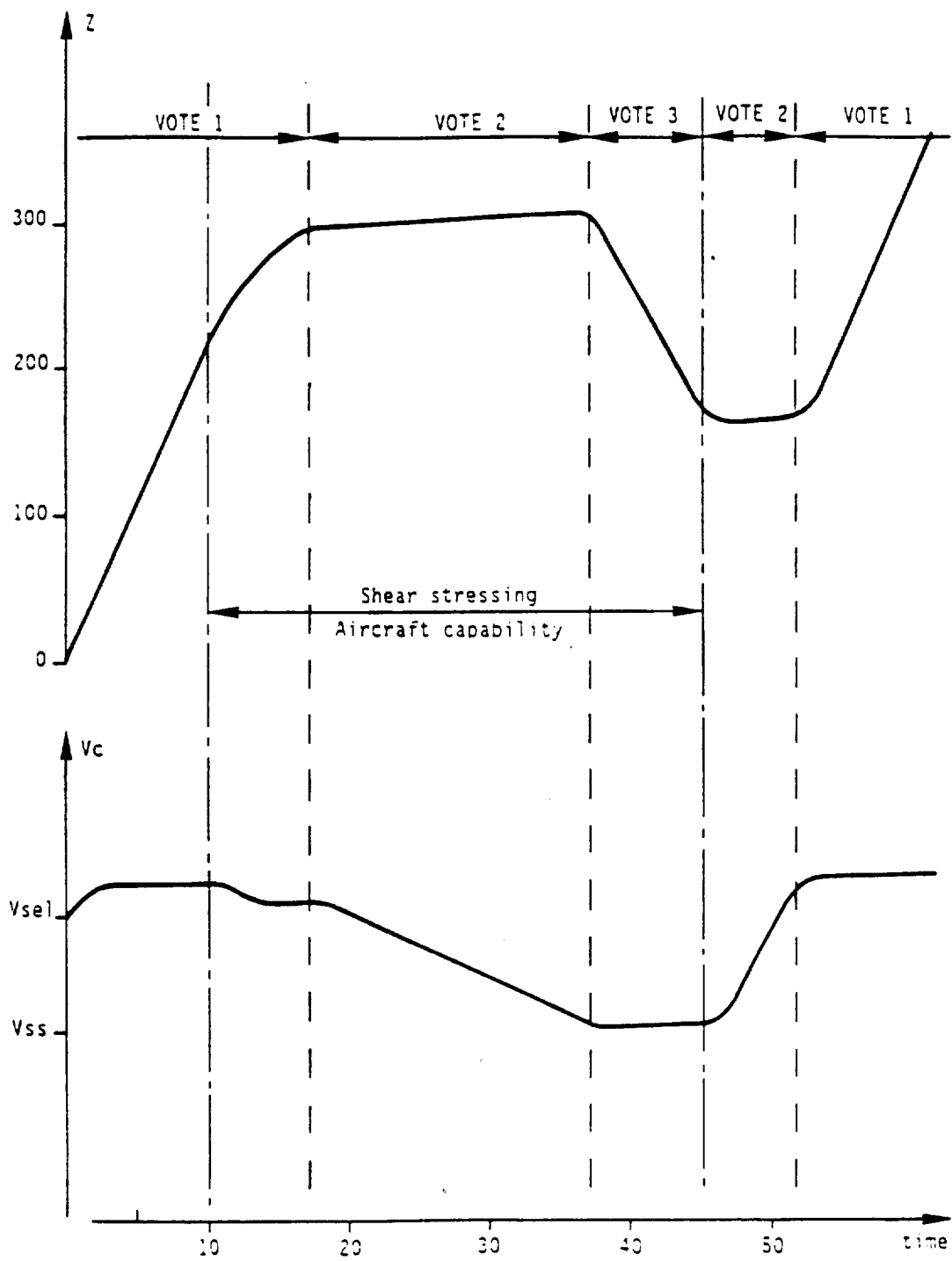
## SHEAR CONDITIONS

3	Shear does not stress  aircraft capability	Strategy 1 or 2 will control AC according to shear intensity and thrust to weight ratio
4	Shear intensity  stresses aircraft  capability	Control strategy is self adapted to AC flight parameters : <ul style="list-style-type: none"> <li>1 - VC = <math>V_2 + 10</math> Kts control (<math>VZ \searrow 0</math>)</li> <li>2 - <math>VZ \approx 0</math> control (<math>VC \searrow V_{SS} + \Delta</math>)</li> <li>3 - VC = <math>V_{SS} + \Delta V</math> control (<math>VZ &lt; 0</math>)</li> </ul> until shear decreases.

Figure2







# S.R.S. SURVIVAL STRATEGY

Figure 4

TAKE-OFF F / S 20 / 20 M = 150 t XG = .25  $V_2 = 154$  Kts

AC 120.41 WIND FIELD Nr 6

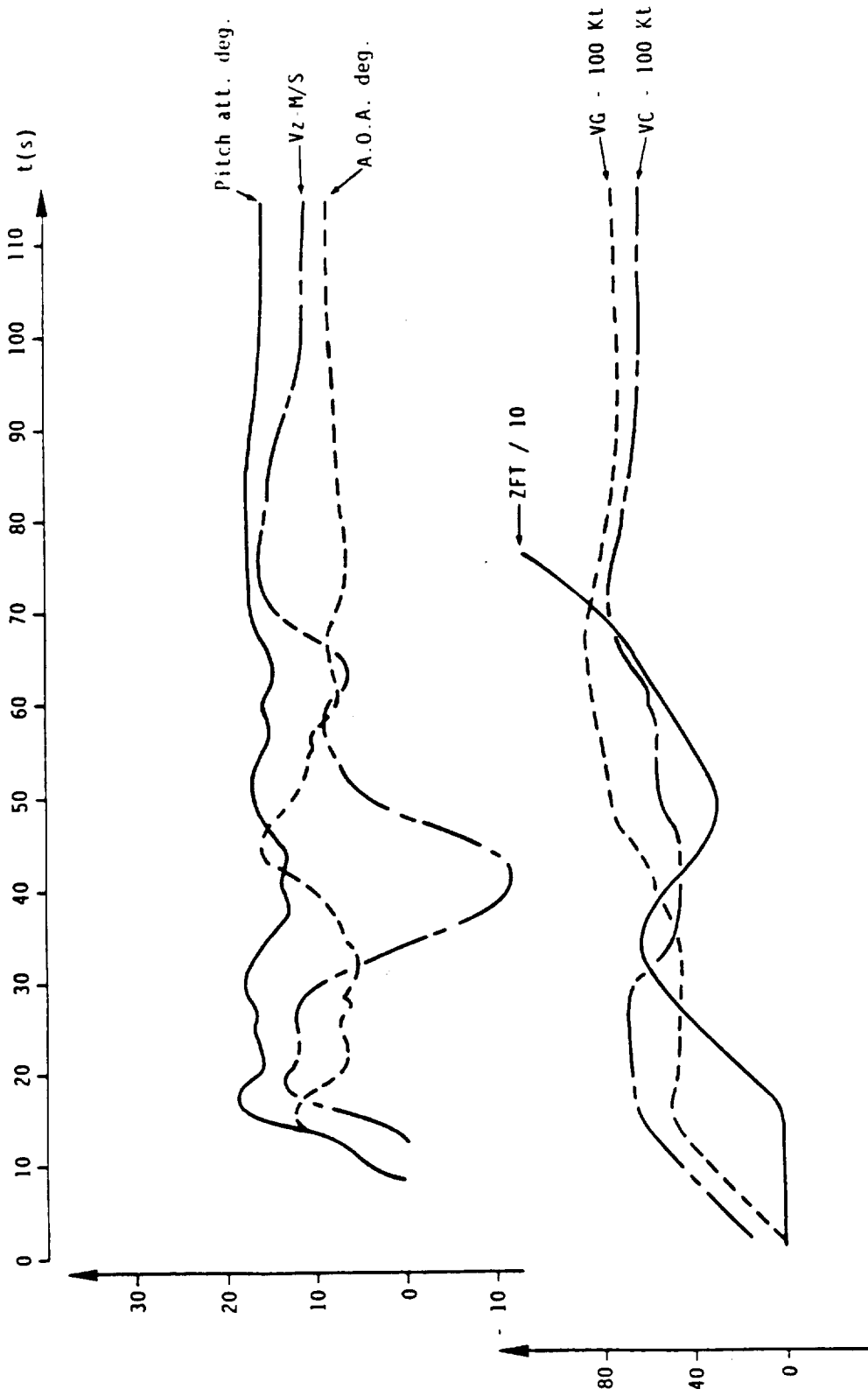
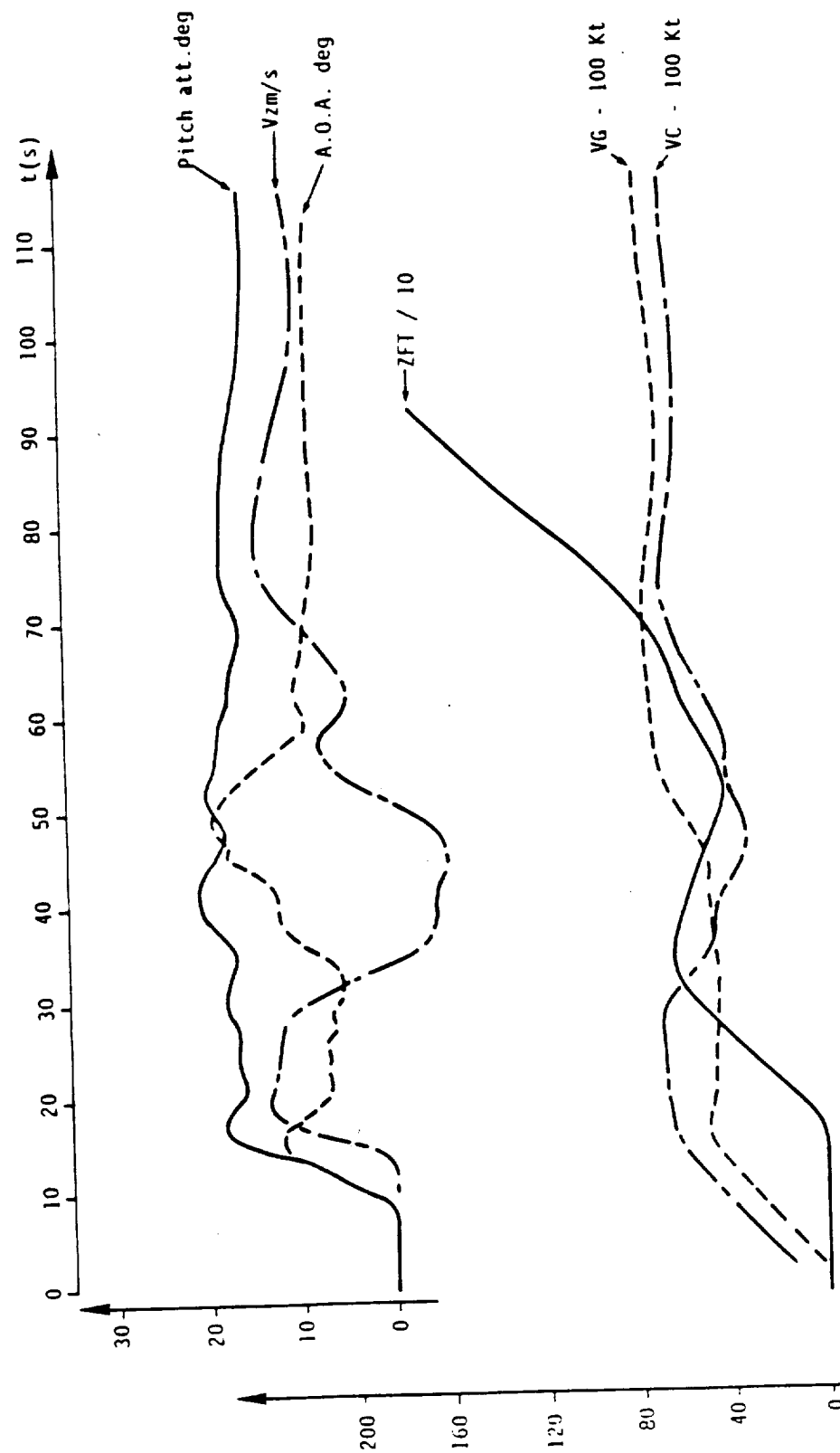


Figure 5

TAKE-OFF F / S 20 / 20      M = 150 t      XG = .25      V<sub>2</sub> = 154 Kt/s

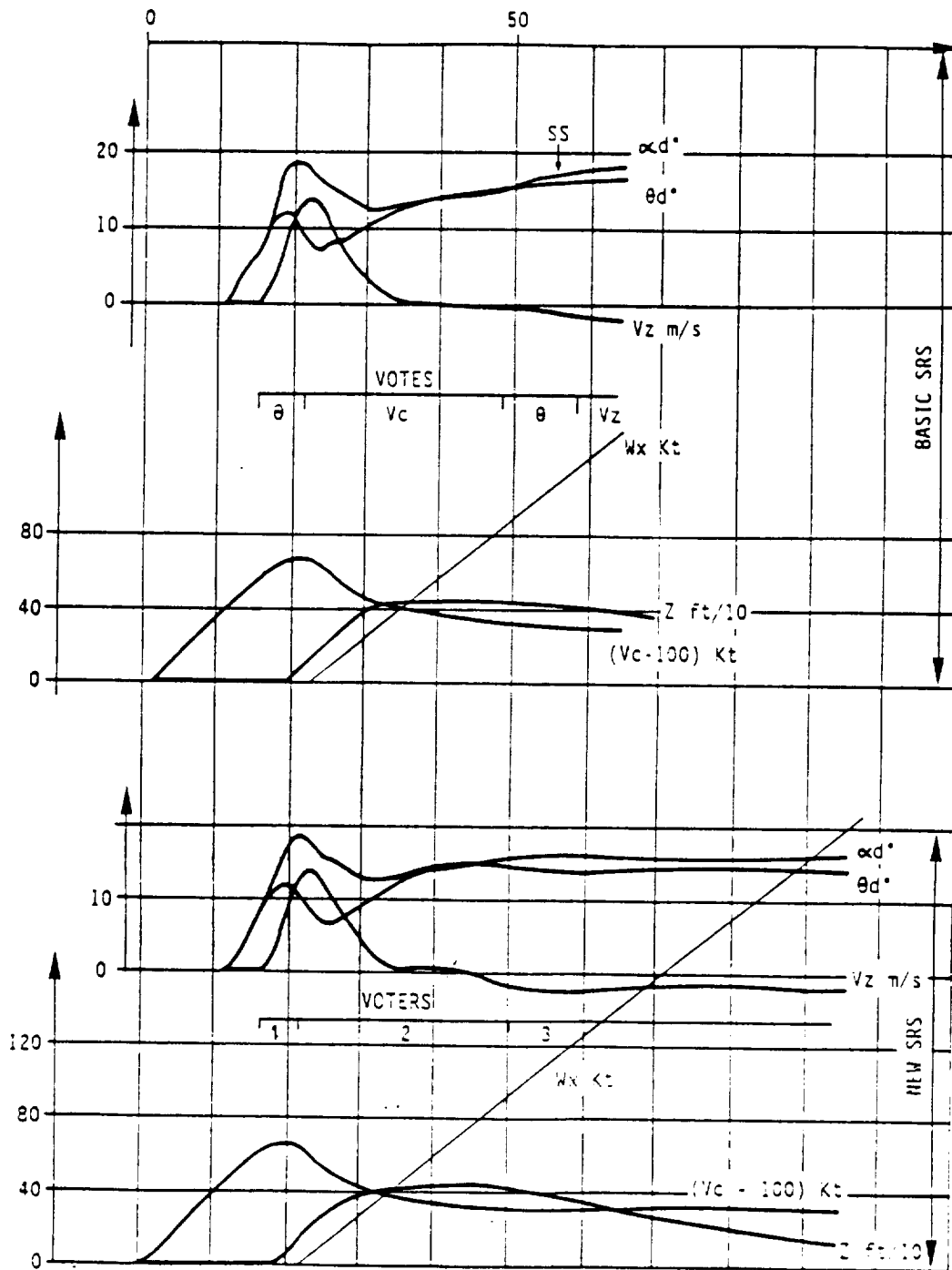
AC 120.41 wind field Nr 6



CONTROL OF AIRCRAFT'S ENERGY

Figure 6

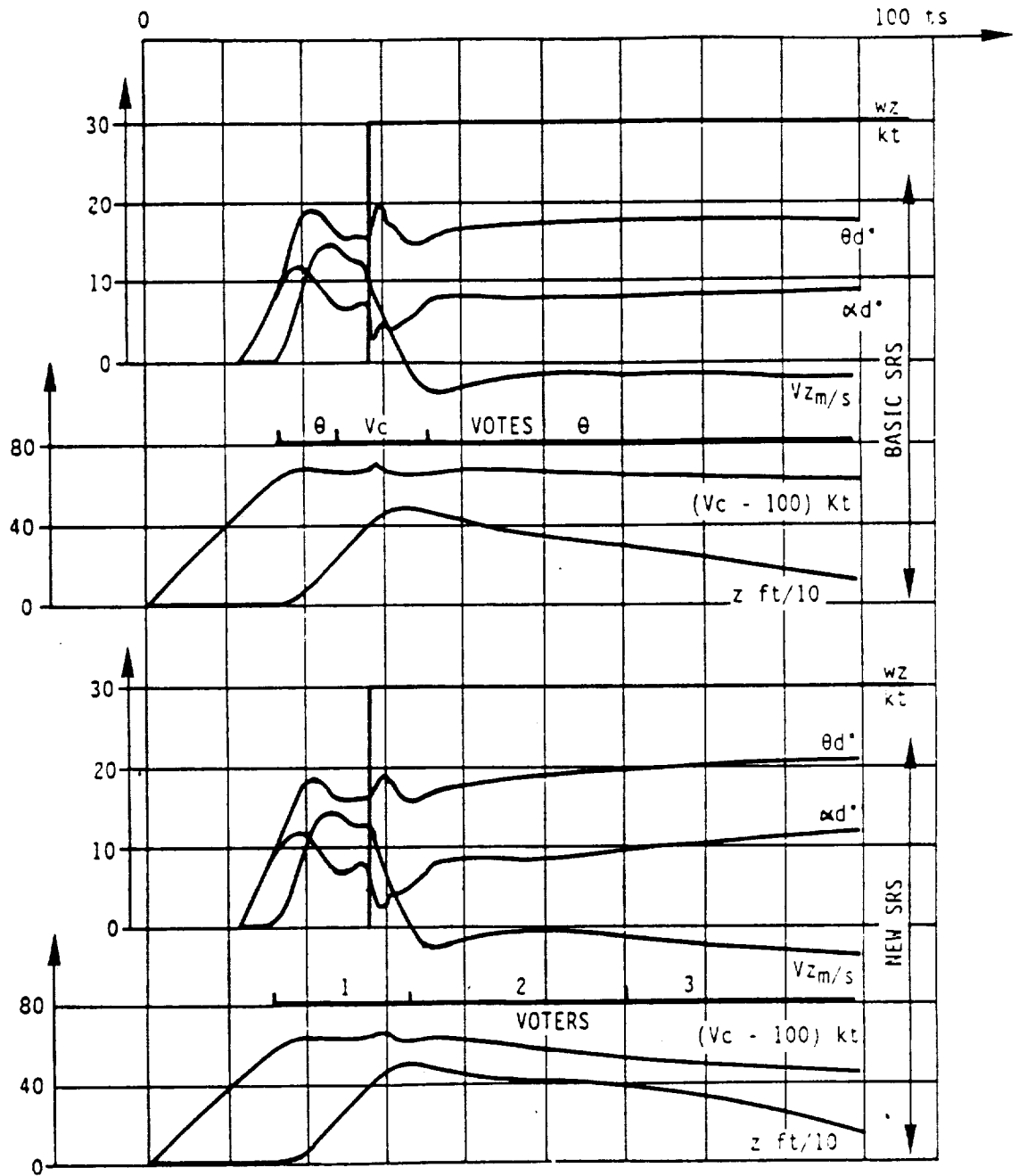
TAKE-OFF ± ISA . SL



LONGITUDINAL TAIL SHEAR

Figure 7

TAKE-OFF ISA-SL



VERTICAL DOWN WIND

Figure 8

## AIRBUS WSM SYSTEM TARGETS

### Performance

- Detect  $10^{-6}$  or  $< 10^{-6}$  simulated cases
- If no detection show the good behaviour of the aircraft

### Nuisance

Warning due to active Failure

$5 \cdot 10^{-6}$ /approach or take off

Lack of warning due to latent Failure

$6 \cdot 10^{-6}$ /approach or take off

Performance nuisance warning

$10^{-6}$ /approach.

Figure9

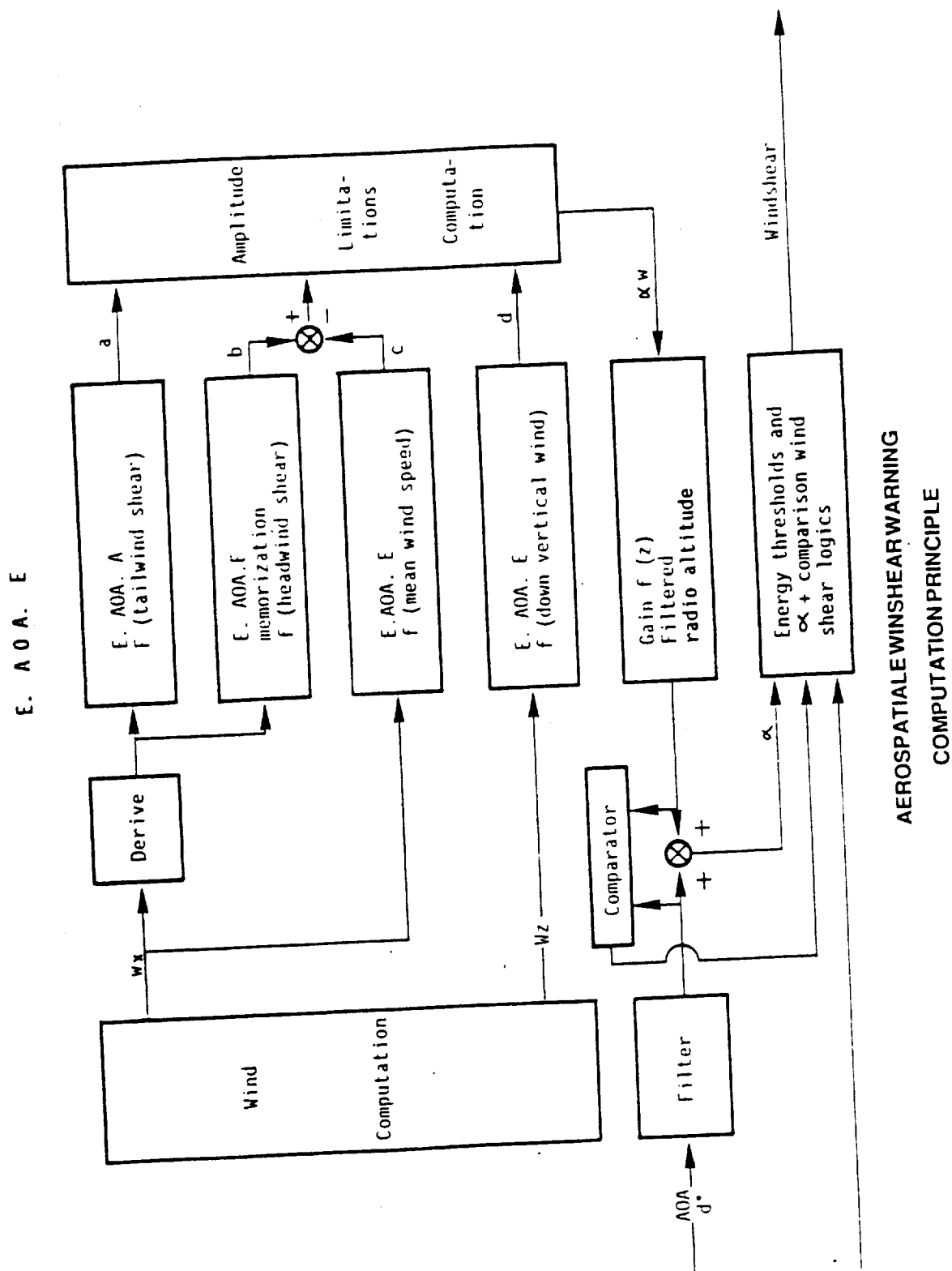


Figure 10



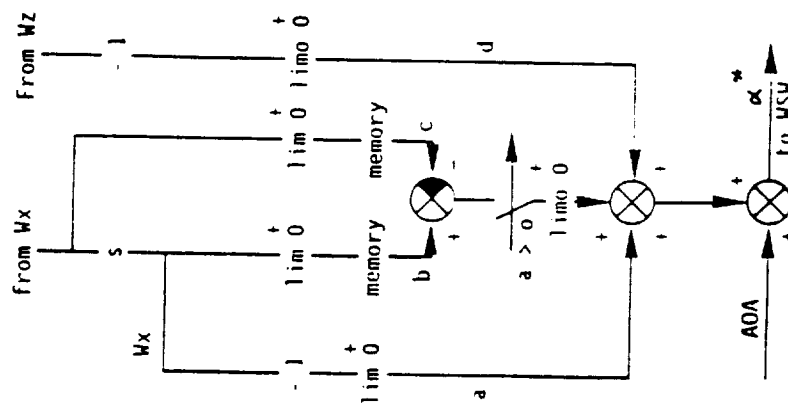
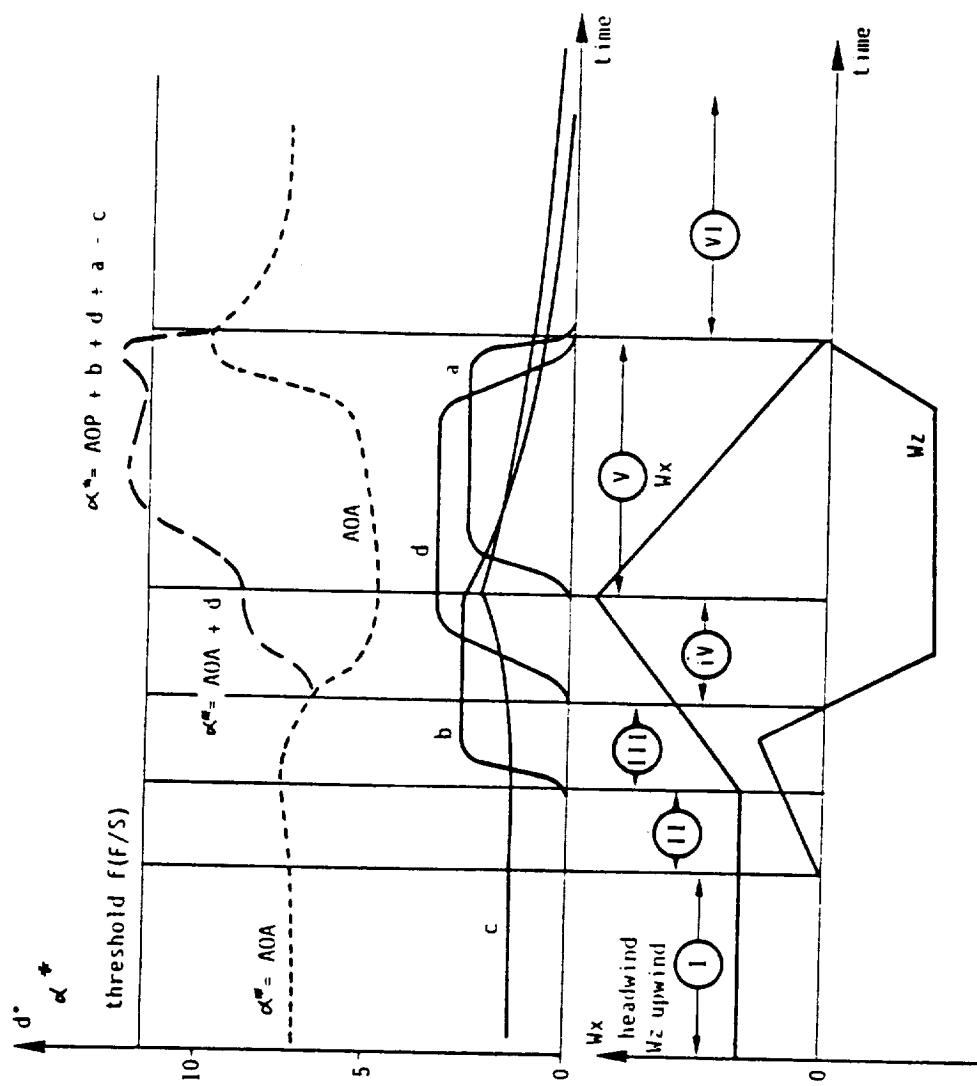
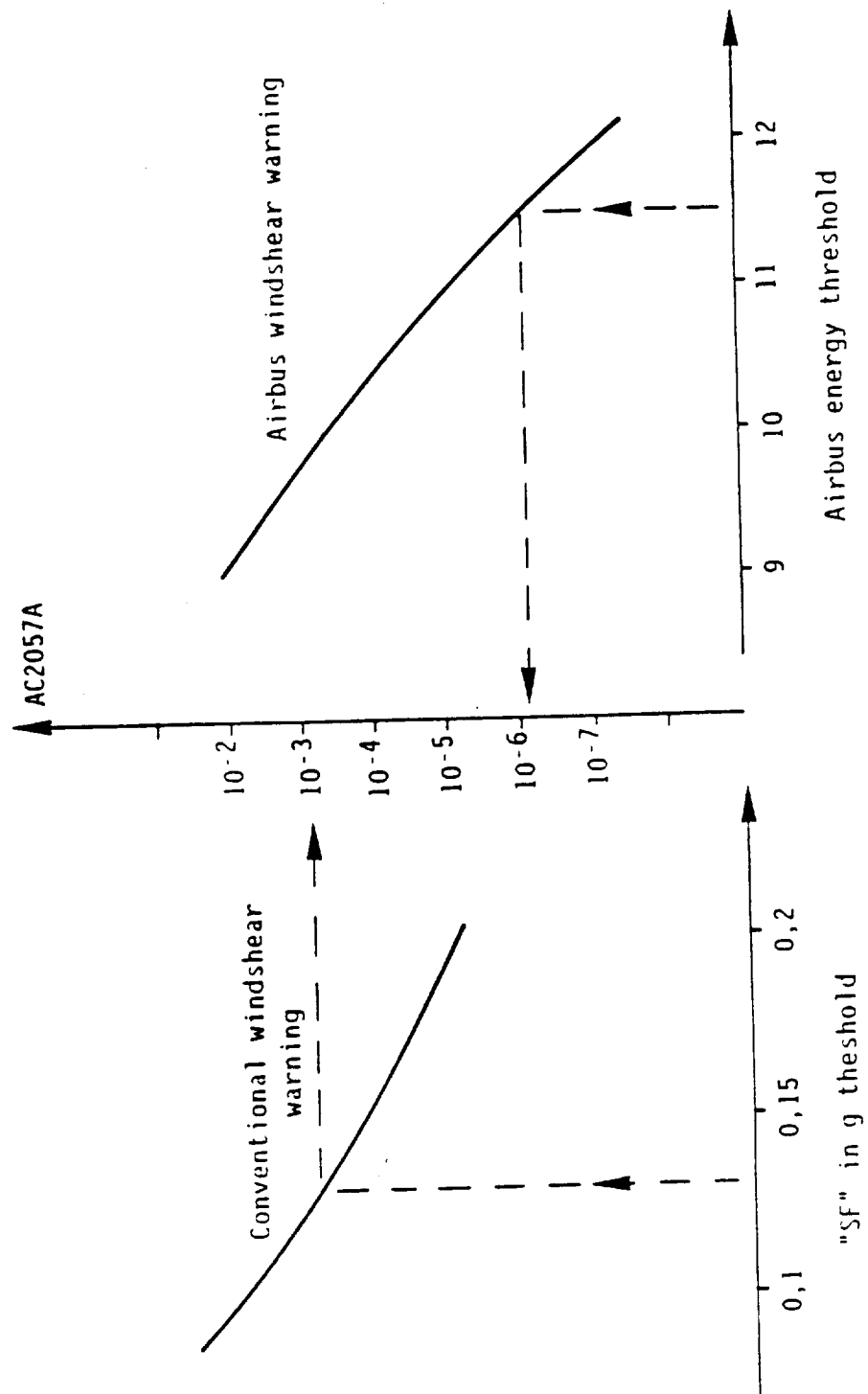


Figure 11

SIMPLIFIED ALGORITHM

# NUISANCE WARNING PROBABILITY



LANDING CASE

Figure 12

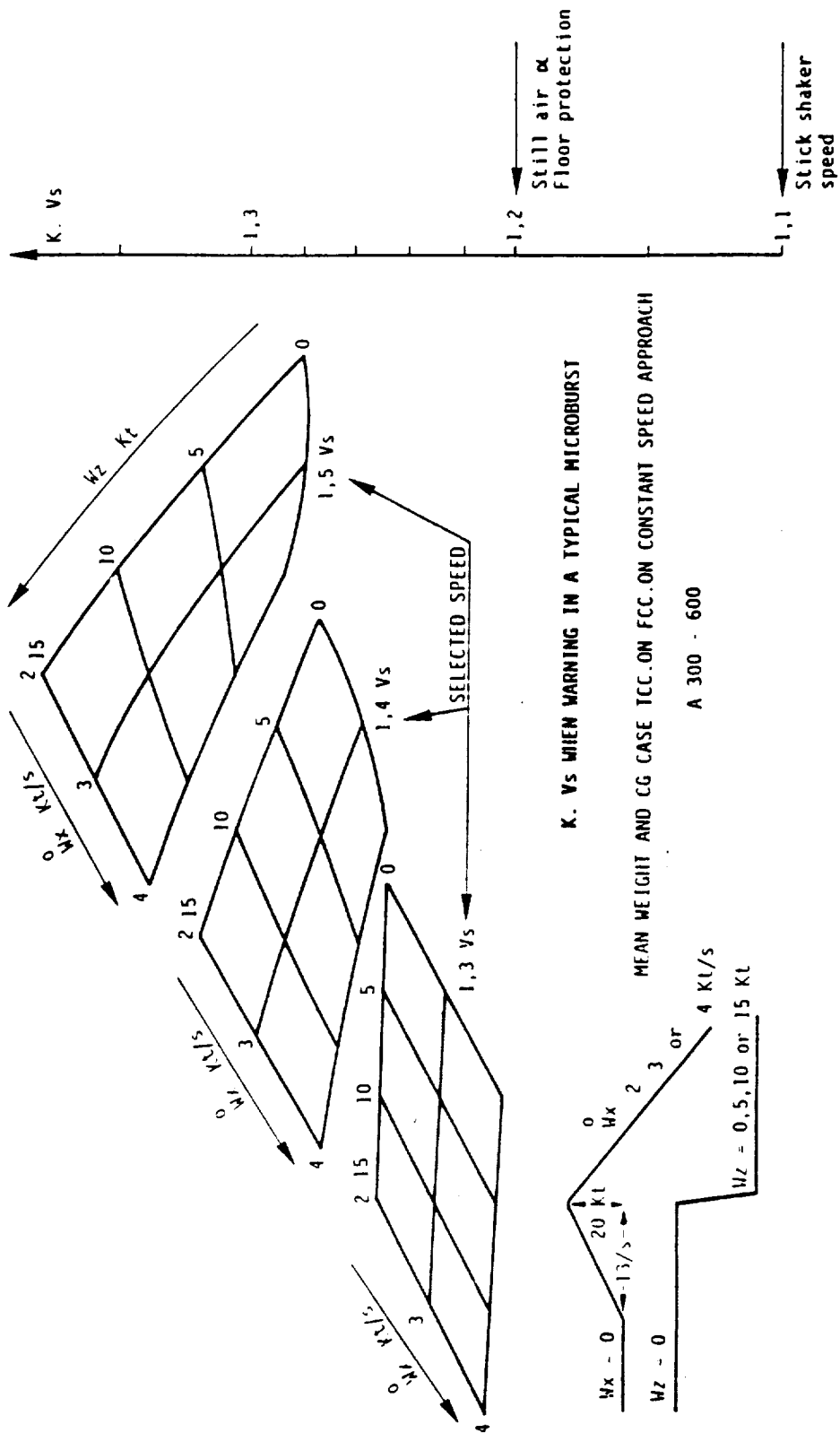
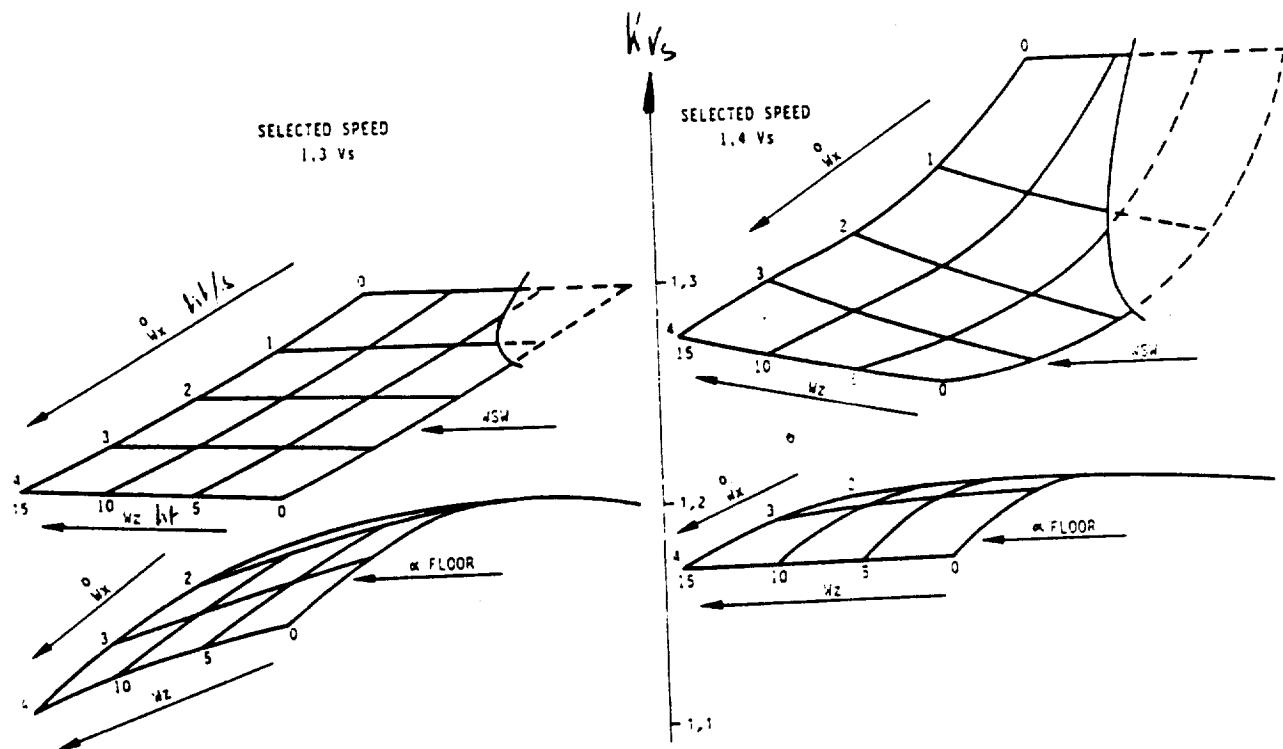


Figure 13



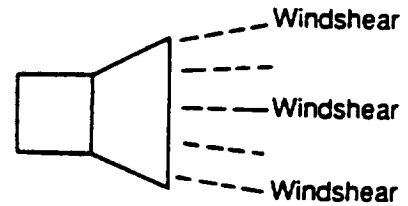
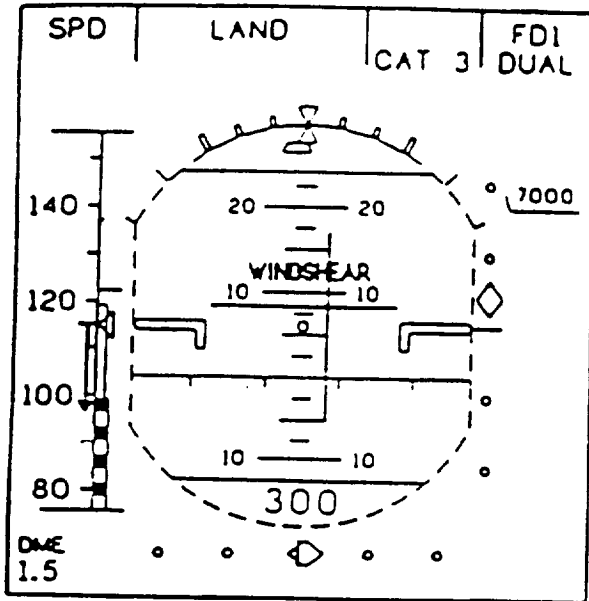
MEAN WEIGHT AND CG CASE TCC ON FCC CMD  
 CONSTANT SPEED APPROACH A300-600  
 TYPICAL MICROBURST

Figure 14

## GROUND TEST

1 or 2 FAC ENGAGED

Engine not running, perform Lamp test



Windshear encounter non clean config.

and (from take off to 1000 Ft

or from 1000 Ft to 50 Ft)

and WSW available

1 or 2 FAC ENGAGED

**Aural** : Windshear 3 times when WSW gets on either FAC 1 or 2.

**Visual** : Windshear red on both PFD when WSW gets on either FAC 1 or 2 until WSW condition gets off both FAC 1 and 2 plus 15 s.

## AUDIO AND VISUAL WSW

Figure 15

